ACOUSTIC MONITORING OF FLOW THROUGH THE STRAIT OF GIBRALTAR: DATA ANALYSIS AND INTERPRETATION

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LONG-TERM GOALS

Existing techniques do not begin to exploit the full potential of acoustic remote sensing methods to study ocean thermal structure and circulation. This research is intended to improve our understanding of acoustic propagation in shallow-to-intermediate depth environments and to extend tomographic techniques to ocean regimes in which acoustic propagation is more complex than the largely deep water cases studied to date.

OBJECTIVES

Understanding the acoustic forward problem in complicated environments is a prerequisite to using tomographic methods. The conditions in the Strait include substantial variability on short time and space scales, including internal bores and trains of interfacial internal waves. The specific issues that need to be addressed are: (i) to find out whether one or more acoustic ray paths exist (at 2 kHz) that are resolvable, identifiable, stable, and that provide useful integral measures of the flow; (ii) to measure acoustic scattering due to the internal wave bores in the Strait; and (iii) to study normal mode propagation (at 250 Hz), including the feasibility of using modal analyses, matched field tomography, and full-field inversion techniques to obtain information on the temperature and current fields. At the conclusion of the analyses we expect to have a much better understanding of acoustic propagation in the complex oceanographic environment present in the Strait of Gibraltar and, by extension, in other straits that are two-layer systems. We also expect to have determined which of the various possible acoustic methods for monitoring the transport in the Strait works best, and just how well the various methods tried do work.

APPROACH

We are focusing on the use of differential travel times (at 2 kHz), horizontal ray arrival angles (at 2 kHz), and normal mode group delays and amplitudes (at 250 Hz) as the observables to use in the inverse problem for ocean sound speed and current, using data from a short-term feasibility test conducted during April-May 1996. Extensive independent measurements of the temperature, salinity, and velocity fields in the Strait were made. Satellite synthetic aperture radar (SAR) images of the Strait were acquired to provide information on the evolution of the internal wave bores. Three current meter moorings provided data spanning the Strait near its eastern end. We plan to do extensive

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forward modeling of the acoustic propagation in the Strait, using a variety of propagation codes and a 4-D synthesis of the sound speed and current meter data. Good matches will both help to explain the acoustic observations and allow us to extract more information from inverse methods.

WORK COMPLETED

Analysis of the data collected during FY96 continued throughout FY97. The data processing tasks completed include processing of the received data to improve the signal-to-noise ratio, generating and applying clock and mooring motion corrections, and generating time series of travel times between the 2-kHz instruments. The transceiver geometries were selected to give lower ray paths entirely confined to the (lower layer) Mediterranean water and one or more upper ray paths that traversed the interface and sampled the (upper layer) Atlantic water. With one exception, time series of the travel times have been generated at present only for the lower paths due to the complex structure of the upper path arrivals. In addition, acoustic survey data have been processed to determine the locations of the 2 kHz instruments and the transponders used to track the 250 Hz vertical receiving array. Finally, echo-sounder data acquired during the experiment have been processed to obtain detailed bathymetric profiles between the acoustic instruments.

Sum and difference travel times have been computed for the lower paths and preliminary estimates made of the sound speed perturbations and current components parallel to the acoustic paths. The phase differences between two horizontally separated receivers have been computed for the lower path as a first step in using horizontal arrival angle fluctuations to measure the current perpendicular to the path. A preliminary attempt to use scintillation techniques to measure the current has also been made.

Sound speed sections have been prepared from the CTD data. Measured arrival patterns have been compared with ray predictions.

RESULTS

The first arrivals, from the lower ray paths, are resolvable, identifiable, and stable. The sum travel times for the lower paths are remarkably stable over a two-week period, with a slow peak-to-peak change of only about 3 ms, roughly corresponding to an integrated sound speed change of about 0.3 m/s and a temperature change of about 70 m° C, reflecting the relative stability of the temperature of the outflowing Mediterranean water. The difference travel times show a much larger signal, with a peak-to-peak tidal variability of about ± 5 ms, roughly corresponding to integrated currents of about ± 50 cm/s. The differential travel times are consistent with the directly measured currents.

The upper path arrival structures and travel time fluctuations are complex. These paths traverse the interface between the Atlantic and Mediterranean waters, and so include significant baroclinic effects. The tidal travel time fluctuations for the upper paths are not nearly as sinusoidal as for the lower paths, but instead tend to have a distinctly sawtooth character, as a result of propagation through the internal bores and trains of interfacial internal waves generated on each tidal cycle. The tilt of the instrument on the south side of the Strait clearly shows the times at which the internal wave bores pass the instrument. This means that the times of the bores'passage are precisely known, making it possible to interpret the acoustic data using deterministic models of the bores. The reciprocal data show that the arrivals from the upper paths are similar in structure for transmissions perpendicular to the Strait, but are significantly different for transmissions diagonally across the Strait. The non-reciprocity in arrival structure for the upper paths is significantly greater than that previously observed at a similar range and frequency in mid-ocean, affecting our ability to use the upper path arrivals to measure sound speed and currents.

The measured time series of phase difference between the two horizontally separated receivers for the lower path is clearly correlated with phase differences predicted using the current meter data. Although the measured phase difference series is noisy, these results are encouraging.

Preliminary results at 250 Hz show that the arrival pattern is a strong function of depth, as expected. The arrival pattern changes relatively slowly with time, suggesting that amplitudes may well contain useful information about the ocean. This is not unexpected, as the propagation should be unsaturated at this short range and low frequency.

A conference paper summarizing the results as of April 1997 is in press (Worcester et al., 1997).

IMPACT/APPLICATIONS

This research has the potential to affect the design of acoustic systems that must function in complex two-layer environments such as the Strait of Gibraltar, whether for acoustic remote sensing of the ocean interior or for other applications. Internal wave bores, in particular, appear to be more ubiquitous in shallow water than previously realized, making a full understanding of their impact on acoustic propagation crucial to predict the performance of acoustic systems.

Monitoring the variability of the transport through the Strait of Gibraltar is important for a wide range of oceanographic problems. Acoustic methods have the potential to directly provide spatially-averaged measures of the flow, and are therefore strong candidates for providing routine, rapidly repeated, transport measurements. If this research is successful, it could lead to the application of acoustic methods for long-term monitoring of transport in the Strait of Gibraltar and, by extension, in other similar straits.

TRANSITIONS

None.

RELATED PROJECTS

A preliminary equipment test in Knight Inlet was part of a much larger Knight Inlet Experiment led by D. Farmer (IOS, Canada). The Strait of Gibraltar experiment is a joint effort with U. Send (University of Kiel, Germany). In addition, we are collaborating with J. Apel (Global Ocean Associates), who is analyzing the SAR images.

REFERENCES

Worcester, P. F., U. Send, B. D. Cornuelle, and C. Tiemann, "Acoustic monitoring of flow through the Strait of Gibraltar," Proceedings of the Shallow Water Acoustics Conference 1997, Beijing, China, April 21–25, 1997 (in press, 1997).